# Assessment of central visual functions in patients with low vision: a review of commonly used tests and strategies

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## Abstract
The measurement of distance visual acuity is the most familiar and most widely used test of visual function. However, this is only one in a battery of tests used in the assessment of patients with visual impairment. A full and comprehensive assessment helps to build a picture of the need and urgency for further treatment, including the provision of rehabilitative interventions and to predict the performance of low-vision devices.

This review outlines some of the principal tests and strategies available for the clinical assessment of visually impaired patients that are readily available to practising optometrists. The generic principles of the key visual functions assessed in the low-vision assessment are outlined, together with a critical review of those instruments still currently used within optometric practice which may not yield the most reliable results.

Improving the accuracy of visual assessment will improve referral refinement, support decision making and assist in prescribing the most appropriate solutions for visually impaired patients.

## Introduction
As eye care practitioners, we are in a strong position to assist patients who have low vision as part of a multidisciplinary healthcare team and, over recent years, an increasing number of practitioners have begun incorporating low-vision management as a core optometric service for their growing elderly patient base. To provide this service our management and prescribing decisions must be made using accurate, reliable and repeatable methods. However these methods should also be cost-effective, easy to administer and as simple to interpret as those tests we use with our normally sighted patients.

This article outlines some of the principal tests and strategies available for the clinical assessment of visually impaired patients that are commonly used and readily available to practising optometrists. The tests and strategies are not necessarily restricted for use by specialist low-vision centres. The generic principles of the key visual functions assessed in the low-vision assessment are discussed together with a review of those instruments most commonly used in current optometric practice.

## Distance visual acuity
Although the limitations of the Snellen chart in measuring high-contrast distance visual acuity have been well documented (Elliott 2016; Lovie-Kitchin 2015), it still remains the test of choice for a large body of healthcare professionals. The reluctance to change seems to be firmly rooted in familiarity and habit and is not just down to the cost of changing to a more reliable and accurate method of testing visual acuity.

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Bailey and Lovie successfully addressed the design flaws ingrained within the Snellen chart (Bailey and Lovie-Kitchin 1976). The Bailey–Lovie charts introduced letter sizing following a logarithmic progression. As the patient reads down the chart the only variable that changes is the angular subtense of the letters. All other variables that influence the measurement of visual acuity remain the same, including the following.

**Line scaling and line spacing**
To maintain the same degree of contour interaction throughout the chart, the between-row spacing is equal to the height of the letters in the smaller row and adjacent letter spacing is equal to one letter width. The scale of optotype sizes decreases in 0.1 logMAR steps.

**Optotype and line legibility**
For each line to be of equal difficulty both the number of optotypes per line and the overall line legibility should remain constant (National Research Council 1980; Sloan et al. 1952). The optotypes used are either British Standard letters, consisting of D E F H N P R U V Z C and K (BSI 4274- 1 2003), or Sloan letters, consisting of C D H K N O R S V Z (Sloan 1959).

**Test distance**
When assessing low visual acuity, it is often necessary to use the chart closer than the standard working distance. Working distance should be reduced when the patient's acuity is limited to the top row of letters, since the top and bottom rows do not have full contour interaction without having another line either above or below, respectively. When moving a logMAR chart closer to the patient by half the standard distance, a correction factor of +0.30 logMAR is added to the overall acuity score. Care should be taken when using charts at very close working distances as a small change in head or body posture can make a significant change in the distance between the patient and the chart. This is particularly relevant when testing patients with a central scotoma or patchy media as they often move their head and body to catch an eccentric view of the chart.

**Methods of scoring**
One of the barriers to changing to a logMAR chart has undoubtedly been the need to change to a new method of scoring visual acuity measurements. When assessing Snellen acuity, patients tend to be given credit for a whole line of letters rather than for individual letters seen. With some lines having more letters than others, this method is inconsistent, particularly when fewer letters are available for recording low acuities. One of the many advantages of using a logarithmic progression of letter sizing is that equal credit may be given for every letter read correctly (e.g. 0.02 logMAR is awarded for each of the five letters on each line of a standard Bailey–Lovie chart). Low visual acuities may then be measured and scored as accurately as higher levels of acuity, assisting comparison between successive visits (Ferris and Bailey 1996). It is still acceptable additionally to record final acuities in equivalent Snellen notation and most logMAR charts will have Snellen acuities printed alongside the logarithmic scale to assist conversion. When recording a converted acuity score, the original test chart design should also be recorded.

**Test–retest variability**
It is not unusual for practitioners to see fluctuations in visual acuity measurements with no obvious change to the underlying pathology (Raasch et al. 1998). Test–retest variability (TRV)

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quantifies this variability in results when the test is repeatedly administered to the same individual even in the absence of true clinical change.

TRV is influenced by a number of factors, including chart design and methods of testing such as termination (i.e. when to ask the patient to stop) and scoring rules. For example, there may be significant interpractitioner variation due to differences in levels of encouragement of the patient (Carkeet 2001).

Published values suggest that the TRV of logMAR charts when scored letter by letter for subjects with normal vision requires a change of 0.12–0.18 logMAR for the practitioner to be con dent of a clinically significant change in vision (Hazel and Elliott 2002; Lim et al. 2010; Rosser et al. 2001). In comparison, the TRV for a Snellen chart is significantly higher at ±0.33 log units (equivalent to three rows of a logMAR chart) using the more commonly used row-by-row scoring (Rosser et al. 2001). Additionally, TRV is greater with optical defocus (Rosser et al. 2004) and in patients with age-related macular degeneration (Patel et al. 2008).

## Charts used in the assessment of distance visual acuity

### The Bailey–Lovie chart (Figure 1)

The first logMAR acuity charts were developed by Bailey and Lovie in 1976 and went into production in 1978 (Bailey and Lovie-Kitchin 1976). The standard working distance is 6m, and they are externally illuminated with a tolerable luminance range of 80–320cd/m2, within which visual acuity testing may be performed (Sheedy et al. 1984). The design principles of the Bailey–Lovie chart have been used to produce a range of similar charts using a wide range of symbols.


**Figure 1.** Bailey–Lovie charts are 53 × 61cm with British standard optotypes presented in a logMAR progression. The minimum angle of resolution (MAR) is taken as the stroke width of the letter, which is one- fifth of the letter's vertical subtense when printed in a 5 × 4 presentation. Recommended luminance for acuity testing is 160cd/m2.

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## ETDRS chart (Figure 2)

Three charts were developed for use in the Early Treatment Diabetic Retinopathy Study (ETDRS) (Ferris et al. 1982), following the same design protocols of the original logMAR acuity test charts. Lines with similar overall difficulty were created for use in charts 1 and 2 for presentation to right and left eye respectively. Chart R is recommended for refraction. The original three charts were revised in 2000, and now incorporate a slight change in the difficulty score for each of the 10 Sloan letters used.

The ETDRS has the advantage over the Bailey–Lovie chart in maintaining consistent illumination; however, the light box into which the test cards are slotted is large and may take up space in a small consulting room. In comparison, the Bailey–Lovie chart takes up little space, although it may be slightly more difficult to achieve even illumination.

## The Berkeley Rudimentary Vision Test (BRVT) (Figure 3)

The limit of the ETDRS is 1.60 logMAR using the chart at the closest recommended working distance of 1m, and for the Bailey–Lovie chart is 1.40 logMAR at 1.5m. For recording lower levels of visual acuity there has not been a widely accepted method, with many eye care professionals still opting to use an unstandardised 'counting fingers' or the commonly used motion detection test, 'hand movements', when the limit of a standard test chart is reached. However, accurate measurement of severe visual impairment is still important to detect change due to underlying pathology and to consider the need for mobility or rehabilitative services.

The BRVT has been designed to offer a method of testing very low acuity levels (Bailey et al. 2012; Bailey and Lovie-Kitchin 2013), extending the range of measurable acuity to 2.90 logMAR and then to perception of light.

Ideally, a logMAR distance chart should be used to assess all patients with low vision. Both the ETDRS and Bailey–Lovie charts are ideal for this purpose and have similar repeatability. Together with the BRVT, an accurate assessment of all levels of distance vision may be quickly scored in logMAR, with a simple conversion to the more familiar Snellen equivalent if preferred.

## Reading performance

For the majority of patients with low vision, reading is their most important goal. Many daily living tasks rely on the need to see small physical print sizes of varying degrees of contrast whilst the need to tackle a fluent reading task can be more complex, taking into consideration a number of factors that affect reading speed and fluency.

Although distance and near acuities are related, they are not equivalent (Lovie-Kitchin 2011). Reading is also a more complex task involving visual sensory input, accurate eye movements and higher cognitive aspects of comprehension (Latham and Whitaker 1996; Lovie-Kitchin 2011), thus a multifaceted assessment is required to set realistic and achievable goals for an individual with low vision.

## Physical print size or angular print size?

Angular print size refers to the angular subtense of print on the retina and is recorded in logMAR when measuring near acuity clinically. Angular print size takes into consideration both the

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physical print size and the working distance at which the print is held, therefore the working distance at which the chart is held should always be recorded.

The physical print size is a description of the actual size of the printed text on the page and therefore remains unchanged regardless of working distance. The physical print size is more functionally relevant to the patient whose goal may be to read a specific size of text such as newsprint.

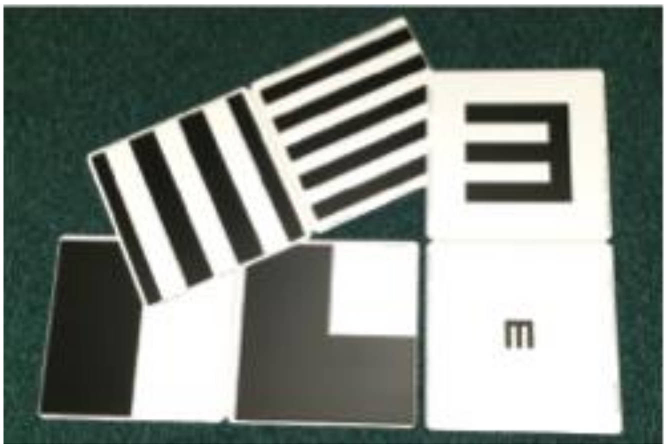

**Figure 3.** Using three sets of cards, the Berkeley Rudimentary Vision Test (BRVT) extends the range up to 2.60 logMAR using single tumbling E optotypes up to 2.90 logMAR using gratings. Beyond this level, the additional cards of white field projection (WFP) and black/white discrimination (BWD) are the last in a battery of 13 increments that test from the limit of spatial vision to the perception of light.


**Figure 2.** The Early Treatment Diabetic Retinopathy Study (ETDRS) charts use Sloan optotypes silk-screened on a non-reflective translucent panel in a 5 × 5 grid pattern. Charts are slotted into a light box containing two fluorescent lamps. Charts are now available in Landolt C, tumbling E and Patti Pics symbols and for use at baseline working distances of 4m, 3m and 2m.

Physical print sizes include the familiar N-point notation or Sloan M units. The M unit designates the distance (in metres) at which the object subtends 5' arc. Bailey and Lovie-Kitchin (1980) measured 1M to be equivalent to N8, although it has been found that the physical print size of the 1M print size incorporated into the MNREAD charts is slightly larger than N10 (Latham and Tabrett 2012).

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Table 1 shows a conversion chart to assist practitioners in understanding the relationship between physical print size and angular print size. For example, a physical print size of N8 is equivalent to an angular print size of 0.4 logMAR when the print is held at 40cm, or 0.6 logMAR when held at 25cm.
A number of visual factors are known to influence reading performance in patients with low vision, specifically acuity and contrast reserves, the number of characters visible within the field of view and scotoma size, where relevant (Whittaker and Lovie-Kitchin 1993). The most significant of these factors is acuity reserve, described as the ratio between the print size of the task and the patient's acuity threshold (near reading acuity). When considering acuity reserve in the context of reading rates, the critical print size is the smallest print size that supports reading at the patient's maximum reading speed (Mansfield and Legge 1996).

An acuity reserve of 1.3:1 (equivalent to 0.1 log unit or one line of a near logMAR chart) is suggested for spot reading and a minimum reserve of 2:1 (0.3 log units or three lines on a near logMAR chart) for fluent reading (Latham and Tabrett 2012; Lovie-Kitchin 2011; Whittaker and Lovie-Kitchin 1993).

When considering these guidelines, the standard near test charts found in optometric practice do not have a range of print sizes wide enough for use with low-vision patients. Many patients may not be able to see the largest print size of N36 or N48. Furthermore, to measure reserves of near acuity, especially when the patient is using a magnification device, the chart may need to present very small print sizes. A near chart that presents a logarithmic progression is also useful in estimating task magnification.

**Estimating task magnification**

The magnification between each line of logMAR acuity is 1.26×, thus for every three lines change (0.3 log units) there is a 2× difference in magnification (Table 2). Alternatively, the magnification required to increase N10 to N40 is 4× and the magnification difference between Sloan 1M and 8M is 8×.

**Table 1.** Conversion chart for near acuity*

| **Physical print sizes** | | **Comparable angular print size** | |
|---|---|---|---|
| N-point | Sloan M unit | LogMAR at 40cm | LogMAR at 25cm |
| 100 | | 1.5 | 1.7 |
| 80 | 10 | 1.4 | 1.6 |
| 64 | 8.0 | 1.3 | 1.5 |
| 48 | 6.3 | 1.2 | 1.4 |
| 40 | 5.0 | 1.1 | 1.3 |
| 32 | 4.0 | 1.0 | 1.2 |
| 25 | 3.2 | 0.9 | 1.1 |
| 20 | 2.5 | 0.8 | 1.0 |
| 16 | 2.0 | 0.7 | 0.9 |
| 12 | 1.6 | 0.6 | 0.8 |
| 10 | 1.3 | 0.5 | 0.7 |

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| | | | |
|---|---|---|---|
| 8 | 1 | 0.4 | 0.6 |
| 6 | 0.8 | 0.3 | 0.5 |
| 5 | 0.63 | 0.2 | 0.4 |
| 4 | 0.5 | 0.1 | 0.3 |
| 3 | 0.4 | 0.0 | 0.2 |
| 2.5 | 0.32 | −0.1 | 0.1 |
| 2 | 0.25 | −0.2 | 0.0 |
| 1 | 0.20 | −0.3 | −0.1 |
| | 0.16 | −0.4 | −0.2 |
| | | −0.5 | −0.3 |

*For example, a physical print size of N8 is equivalent to an angular print size of 0.4 logMAR when the print is held at 40cm, or 0.6 logMAR when held at 25cm. N-point notation is based upon typographic measurements where a point is a printer's measure of 0.0139inch (0.353mm). The closest equivalent of Sloan 1M is N8.

**Table 2.** Magnification factor between successive lines of logMAR acuity

| Lines of improvement in logMAR | Magnification required |
|---|---|
| 1 | 1.26× |
| 2 | 1.6× |
| 3 | 2× |
| 4 | 2.5× |
| 5 | 3.2× |
| 6 | 4× |
| 7 | 5× |
| 8 | 6.4× |
| 9 | 8× |
| 10 | 10× |

## Reading rate

Reading rate rather than near acuity has been shown to be a more relevant outcome measure when assessing low-vision patients with a view to prescribing magnification (Legge et al. 1985). Reading rates vary between patients as a consequence of individual reading abilities; however, a minimum reading rate of 80–100 words per minute (wpm) is considered to be an appropriate guideline for fluent reading, whereas for briefer tasks or spot reading the reading rate ideally should be 40 wpm or more (Lovie-Kitchin and Whittaker 1999; Whittaker and Lovie-Kitchin 1993).

## Example 1

If a low-vision patient has an acuity threshold of N32 (4M; Table 1) and that individual's goal is to read N8 fluently with an acuity reserve of 2:1, then the aim would be to provide sufficient magnification to achieve N4 comfortably (i.e. N8:N4 = 2:1). Theoretically, the magnification required to achieve this would be 8× (N32/N4).

## Example 2

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If a low-vision patient has an acuity threshold of 0.6 logMAR at 40cm (1.6M; Table 1) and that individual's goal is to spot read a task of size 0.4 logMAR (1M), then the aim would be to provide sufficient magnification to achieve the line below this to provide some acuity reserve (0.30 logMAR at 40cm, 0.8M). An improvement of 0.3 logMAR, or three lines, is therefore required, and the magnification theoretically required to achieve this would be 2× (Table 2).

It must be noted, however, that the above values are an estimate and give the practitioner a starting point from which to base an assessment of task magnification. How individuals perform with a magnification device depends upon a number of other clinical and psychological factors. The following near test charts are used frequently in the low-vision setting to assist with either assessing reading rates or task magnification or both.

### The Bailey–Lovie word reading chart (Figure 4)

The Bailey–Lovie near charts are constructed of a similar logarithmic design to their distance counterparts. The use of unrelated words rather than sentences removes contextual cues that influence fluency and which may overestimate reading acuity (Bailey and Lovie-Kitchin 1980).

### The MNREAD near acuity charts (Figure 5)

The Minnesota low-vision reading test (Ahn et al. 1995; Mansfield and Legge 2007) is a continuous text reading chart, using short single sentences printed on to three lines with the level of difficulty standardised by using the same number of characters in each sentence.


**Figure 5.** The Minnesota low-vision reading test (MNREAD) charts show continuous text print from N64 to N1 (8M to 0.13M), reducing in 0.1 log steps from 1.3 to −0.5 logMAR when used at the recommended working distance of 40cm. Charts are also available in reverse contrast. The passages are aimed at individuals who have a reading age of 8 and over. Recommended chart luminance is a minimum of 80cd/m2.

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**Figure 4.** The Bailey–Lovie word reading charts. The charts present a wide range of physical print sizes from N80 to N2 (Sloan 10M to 0.25M) and in a logarithmic progression from 1.6 to 0.0 logMAR when held at 25cm. The charts are available in Times New Roman font, chosen for its widespread use in most newspapers and books.

As with a distance logMAR chart, MNREAD charts can be used at shorter working distances to extend the range of angular acuity that may be assessed (Legge 2011). Changes to the appropriate near correction may be required from the +2.50D addition used at 40cm.

The MNREAD charts have been found to have a TRV of ±0.05 logMAR for reading acuity in normally sighted subjects and a higher value of ±0.10 logMAR in patients with low vision (Subramanian and Pardhan 2006, 2009). TRV values for the Bailey–Lovie word reading chart in normal subjects are ±0.10 logMAR (Lovie-Kitchin and Brown 2000).

## Contrast sensitivity

The measurement of contrast sensitivity has been a well-established test used in clinical and research settings to assist diagnosis and progression of pathological conditions (Pelli and Robson 1988). In the low-vision setting, patients who have significantly reduced contrast sensitivity function report difficulties discerning kerbs and steps, which have implications for the patient's mobility and susceptibility to falls (Morrison-Fokken and Dunne 2014). Contrast sensitivity is also a significant predictor of self-reported activity limitations in daily living tasks (Tabrett and Latham 2011), including reading (Latham and Tabrett 2012).

## Pelli–Robson letter contrast sensitivity chart

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**(Figure 6)**
Sloan letters are printed in 16 triplets of letters, with each triplet having the same level of contrast. The contrast of each triplet progressively reduces by 0.15 log units as the patient reads down the chart, while the size of the letters remains the same (Pelli and Robson 1988).

The original recommended near addition of +0.75DS to compensate for the 1m working distance has since been shown to have no significant influence on results (Latham and Hughes 2013); therefore, patients need only wear their habitual distance correction. Participants are encouraged to read until no letters in a given triplet are read correctly, allowing viewing for at least 15–20 seconds when close to contrast threshold (Elliott et al. 1990a). Contrast sensitivity is scored by giving credit of 0.05 logCS units for each individual letter read correctly after the first triplet (Elliott et al. 1990b, 1991). Results can be described as representing severe, significant or noticeable loss, or normal contrast sensitivity (Table 3).

**Mars letter contrast sensitivity test (Figure 7)**
Whilst the Pelli–Robson chart is widely used in research, it has been less well received in clinical practice, requiring a large wall space with even illumination that may be difficult to obtain in some consulting rooms. The Mars test is portable, easier to store and easier to illuminate evenly. It uses the same set of Sloan letters but contrast declines by letter in 0.04 log unit steps.

With similar design principles, the Pelli–Robson and Mars charts have been shown to have similar repeatability of ±0.21 and ±0.20 log units respectively for both normal and low-vision patients (Dougherty et al. 2005). Normally sighted patients under 50 years of age will have a contrast sensitivity score of 1.80 logCS or better, dropping to 1.65 logCS in the older age group.


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**Figure 6.** The Pelli–Robson contrast sensitivity chart is 59cm wide and 84cm high and is viewed at 1m with a recommended luminance of 85cd/m2. Each letter subtends 2.8° at the recommended viewing distance, which is above acuity threshold for most low-vision patients.


**Figure 7.** The Mars cards are 22.8 × 35.6cm and are intended for use at 50cm, at which each letter subtends 2°. Recommended illumination is 85cd/m2.

**Table 3.** LogCS values for the Pelli–Robson chart with equivalent percentage values

| Loss of contrast sensitivity | Pelli–Robson letter triplet | logCS | Contrast expressed as a % | Pelli–Robson letter triplet | logCS | Contrast expressed as a % |
|---|---|---|---|---|---|---|
| Severe | VRS | 0.0 | 99% | KDR | 0.15 | 63% |
| | NHC | 0.30 | 44% | SOK | 0.45 | 31% |
| Signi cant | SCN | 0.60 | 22% | OZV | 0.75 | 15% |
| | CNH | 0.90 | 11% | ZOK | 1.05 | 7.8% |
| Noticeable | NOD | 1.20 | 5.6% | VHR | 1.35 | 3.9% |
| | CDN | 1.50 | 2.8% | ZSV | 1.65 | 1.9% |
| Normal | KCH | 1.80 | 1.4% | ODK | 1.95 | 1.0% |
| | RSZ | 2.10 | 0.7% | HVR | 2.25 | 0.5% |

In assessing low-vision patients, it has been suggested that, to achieve spot reading of 40 wpm or a fluent reading speed of 80–100 wpm, a contrast reserve of 3× and 10× respectively is required (Whittaker and Lovie-Kitchin 1993). For example, text of 80% contrast could be predicted to be fluently read by someone with 8% contrast threshold (1.05 logCS, boundary of significant/noticeable loss), or spot read by someone with 30% contrast threshold (0.45 logCS, boundary of severe/significant loss) (Table 3).

It has also been shown (Latham and Tabrett 2012) that, for patients whose near acuity is worse than 0.85 logMAR at 40cm and whose goal is to read 1M(N8) with a low-vision device, if their contrast threshold is better than 1.05 logCS (halfway down a Pelli–Robson chart), then 1M is likely to be accessible with a low-vision aid and the patient is likely to achieve a fluent reading rate. If

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worse than 1.05 logCS, then 1M print is less likely to be accessible, even with low-vision aids. Although these guidelines are not completely predictive, they serve as a guide as to whether or not the practitioner should discuss alternative options other than optical magnification to achieve the patient's personal goals. These would include, for example, the use of electronic devices offering contrast enhancement or sensory substitution methods such as audio books.

## Electronic charts, apps and downloads

Computerised charts have been in use in optometry practice and hospital clinics since the 1990s. With the advancement of technology in producing high-resolution images, the large array of tests includes logMAR and contrast sensitivity charts. For use in a low-vision setting, the same design principles as previously discussed must be met, together with appropriate validation, and must conform to the relevant agreed standards.

The advantages of using electronic systems with low-vision patients include the presentation of larger character sizes, randomisation of character or word presentation and automatic scoring. There is no image degradation over time and the portability of using a laptop or tablet favours use over the larger cardboard charts, which are less portable, and which degrade over time. However care must be taken when using smaller screens, which may not allow for appropriate control of contour interaction when presenting large targets and control of calibration is required, especially when producing a chart to measure contrast sensitivity.

## Conclusion

Optometrists have a duty to provide the best service for their patients and therefore using appropriate tests and strategies is fundamental to decision making. The optometrist needs to be aware of the limitations of all tests used in the assessment of both normal and low visual function to be con dent of detecting clinically significant change.

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